A Recalibrated Quarterly Projection Model (QPM 2.0) for India

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The recalibrated quarterly projection model (QPM 2.0) presented in this article is a forward-looking open economy gap model calibrated to generate forecasts, undertake risk assessment and provide policy analysis for the Indian economy. QPM 2.0 augments QPM 1.0 with fiscal-monetary policy interaction, a more nuanced modelling of domestic fuel pricing dynamics, capital flows, exchange rate dynamics and central bank's forex market interventions for a more informed judgement.

The Reserve Bank of India (RBI)'s Quarterly Projection Model (QPM) is a calibrated, forward-looking, open economy, new-Keynesian gap model incorporating specific characteristics of the Indian economy. Its main purpose is to generate medium-term projections and policy analysis consistent with achieving targets/mandate set under the flexible inflation targeting (FIT) framework. The documentation of its predecessor, *i.e.*, QPM version 1 (QPM 1.0) was published in 2016 (Benes *et al.*, 2016a; b). Armed with the lessons of experience, since then, the model structure and parameters were recalibrated to enhance the model with more India-centric characteristics in order to enrich its performance and relevance.[1]

The major enhancements brought about in version 2 (QPM 2.0) are as follows:

a. fiscal-monetary policy interaction;

b. domestic fuel pricing dynamics (oil prices, exchange rates and fuel taxes);

c. capital flows and exchange rate dynamics; and

d. re-parametrisation, incorporating data till Q4:2019 (pre-COVID period)[2].

The rest of the article is arranged into six sections. Section II provides the model structure. The equations and approach to calibration are explained in section III. Model properties in terms of impulse response functions (IRF) are described in section IV. Historical decompositions of major macroeconomic variables are discussed in section V. Section VI presents forecast performance and Section VII concludes.

II. Model Structure

QPM 2.0 embodies the standard new-Keynesian small open-economy framework. It has 6 blocks, *viz.*, i) an aggregate demand block comprising the output gap and credit conditions; ii) an aggregate supply block modelling inflation, inflation expectations and central bank credibility; iii) short-term interest rates (policy reaction function and operating target) and transmission to long-term interest rates; iv) fiscal block; v) the exchange rate *via* the modified risk-adjusted uncovered interest parity condition, capital flows and forex market intervention; and vi) foreign sector block (Chart 1).

II.1. Fiscal-Monetary Policy Interaction

Fiscal policy dynamics can have sizeable effects on output and inflation. Therefore, appropriate modelling of monetary and fiscal policy interaction is vital for improving the understanding of output and inflation behaviour in the context of attaining price stability and sustained growth (Woodford, 2001; Canzoneri *et al.* 2011). Hence, the overall fiscal

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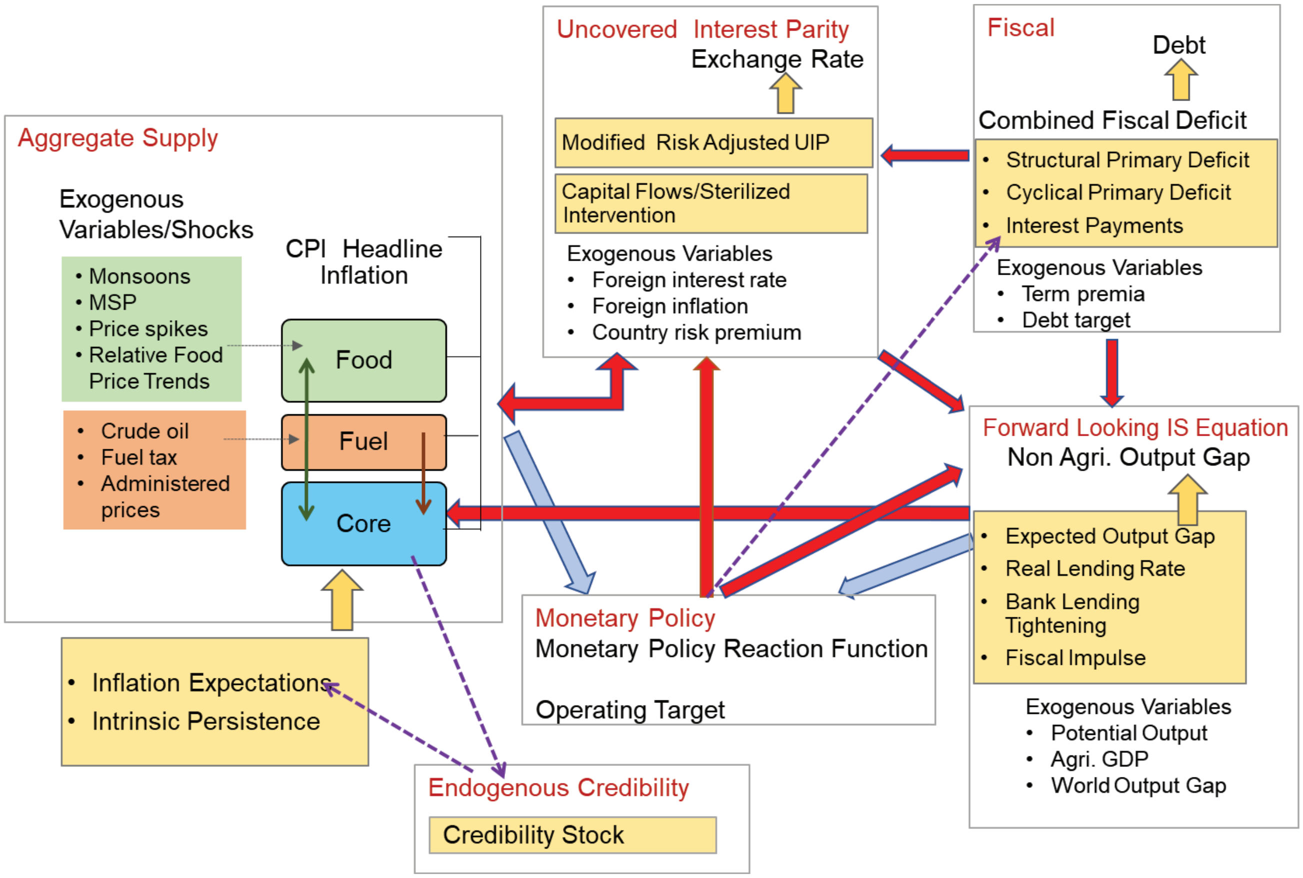
[1] This project was carried out under UTKARSH 2022, the medium-term strategy framework of the RBI.

[2] Data for the period after 2019 were not used as extreme volatility induced by COVID-19 and other developments could affect the average model properties.

Chart 1: QPM 2.0 - Structure



Source: John *et al.*, 2022; Benes *et al.*, 2016b

deficit is decomposed into the primary deficit and interest payments. The primary deficit has structural (cyclically adjusted) and cyclical (automatic stabilisers) components. The cyclical component is modelled as a function of the output gap. Unanticipated changes in the structural deficit in the form of government consumption impacting private consumption and thereby domestic economic cycles form fiscal impulses (Blanchard and Perotti, 2002). Debt dynamics incorporate a) the relationship between debt and the overall fiscal deficit and b) the overall deficit that is compatible with a sustainable level of debt (Escolano, 2010). The steady state structural deficit is linked to the steady state debt level and nominal output growth. Deviations from the long-term debt target affect the country risk premium and the exchange rate through the modified risk-adjusted uncovered interest parity (MRUIP) condition. Changes in aggregate demand and the exchange rate affect inflation, leading to changes in monetary policy. At the same time, monetary policy affects the fiscal deficit through interest payments – short-term interest rate affects long-term rate.

II.2. Fuel Pricing

India has a distinctive system of fuel pricing. Some components of fuel consumption like petrol and diesel are priced on the basis of market variables – international crude oil prices and exchange rates. Some items like liquefied petroleum gas (LPG) and kerosene are market determined but with a lagged pass-through. Prices of another set of fuel items like electricity are administered. Prices of petrol and diesel include a substantial portion of non-*ad valorem* taxes, which impedes the full pass-through of crude oil price changes to inflation. Considering these factors, the fuel section has three different components: a) 'market fuel 1', comprising petrol and diesel prices, is determined by changes in crude oil prices, exchange rates and fuel taxes (excise duty and VAT); b) 'market fuel 2' consisting of LPG and kerosene for which prices are determined by international fuel prices and exchange rates, but with a lag; and c) 'administered fuel' *i.e.*, electricity and other items in the fuel and light subgroup of the CPI. Fuel prices have a substantial role in determining input cost pressures in the economy, which are modelled through spillovers from fuel to non-fuel components of inflation.

II.3. Capital Flows and Exchange Rate Dynamics

The standard approach to capital flows, exchange rates and monetary policy dynamics is based on the 'trilemma' (Mundell, 1963; Fleming, 1962). This was further developed into the new-Keynesian open economy framework, incorporating implications of global financial cycle and dominant currency paradigm (Obstfeld and Rogoff, 2000; Galí and Monacelli, 2005; Gopinath *et al.* 2020; Miranda-Agrippino and Rey, 2022). Volatility in capital flows and exchange rates has implications for macroeconomic management. The orthodox view holds that successful inflation targeting (IT) requires a high degree of exchange rate flexibility. In the context of emerging market economies (EMEs), however, it is observed that it is sub-optimal to overlook the costs associated with volatility in exchange rates due to sudden surges or reversals in capital flows.[3] This has prompted many EMEs to adopt policy tools like forex market interventions for managing exchange rate volatility even under an IT framework (RBI, 2021).

III. Key Behavioural Equations and Calibration

QPM 2.0 has 154 equations (including identities), of which 57 are behavioural equations (Table 1).

III.1. Aggregate Demand: A Forward-Looking IS Curve

Domestic demand is represented by the non-agricultural output gap ($\hat{y}_t^{nag}$), which is defined as the difference between non-agricultural output (y_t^{nag}) and its potential ($\bar{y}_t^{nag}$), expressed in natural logarithms.[4]

$$\hat{y}_t^{nag} = \alpha_1 * E_t(\hat{y}_{t+1}^{nag}) + \alpha_2 * \hat{y}_{t-1}^{nag} - \alpha_3 * \hat{r}_t^{m} + \alpha_4 * \hat{y}_t^{f} + \alpha_5 * \hat{Z}_t - \alpha_6 * \eta_t^{BL} + \alpha_7 * FIMP_t - \alpha_8 * \widehat{rfuel}_t + \varepsilon_t^{\hat{y}^{nag}}$$

$$\alpha_1 = 0.1; \alpha_2 = 0.5; \alpha_3 = 0.25; \alpha_4 = 0.25; \alpha_5 = 0.06; \alpha_6 = 0.4; \alpha_7 = 0.25; \alpha_8 = 0.01. \quad ...(1)$$

where $\hat{y}_t^{nag}$ is determined by its lagged values ($\hat{y}_{t-1}^{nag}$) and model-based rational expectations ($E_t(\hat{y}_{t+1}^{nag})$), long-term market real interest rate gap ($\hat{r}_t^{m}$), global demand captured by foreign output gap ($\hat{y}_t^{f}$), real exchange rate gap ($\hat{z}_t$), bank lending (BL) based on credit conditions (η_t^{BL}), real fuel price gap ($\widehat{rfuel}_t$), fiscal impulse ($FIMP_t$) and shocks to aggregate demand ($\varepsilon_t^{\hat{y}^{nag}}$) (Appendix and Benes *et al.*, 2016b).

Table 1: QPM 2.0 - Dimension

Number of equations	154
of which	
Number of behavioural equations	57
Number of identities	97
Number of variables	154
Number of stochastic shocks	57
Number of measurement equations	33
Number of observed variables	33
Number of parameters	116

Source: Authors' calculations.

[3] In the face of capital flows shocks, the exchange rate tends to move significantly away from its long-run equilibrium, causing exchange rate passthrough to inflation and economic dislocation. Hence, central banks care about the exchange rate in addition to inflation. However, paying attention to the exchange rate using monetary policy tools can undermine the credibility in an inflation targeting regime making monetary policy actions costlier (Blanchard *et al.*, 2016, Ghosh *et al.*, 2016).

[4] All the real trends are system consistent, filtered using Kalman filter. In QPM 2.0, with the incorporation of fuel prices in the aggregate demand equation (equation 1), the world output gap coefficient reflects only the direct effect and has been calibrated accordingly. In QPM 1.0, it reflected the direct effect as well as the indirect impact of crude oil prices.

III.2. Aggregate Supply: Inflation

Considering the unique characteristics of inflation dynamics in India, separate equations are formulated for food, fuel and core[5] components (analogous to the structure of QPM 1.0) (Benes *et al.*, 2016b).

Food inflation (π_t^{food}) depends on its own past (π_{t-1}^{food}). The terms $\left(\pi 4_{t-1}^{headline} - \pi 4_{t-1}^{food}\right)$ and $\left(p_{t+4}^{food} - p_{t+4}^{core} - \overline{rp}_{t+4}^{food}\right)$ ensure that food inflation converges to overall inflation in the long run. In the short run, food inflation is driven by three shocks: monsoon shock ($\varepsilon_t^{monsoon}$); shock to minimum support prices (ε_t^{MSP}); and shock to vegetable prices ($\varepsilon_t^{vegetables}$), each with different short-term effects. The dynamics of these shocks are given by the moving average polynomials $\Gamma_{monsoon}(L)$, $\Gamma_{MSP}(L)$, and $\Gamma_{vegetables}(L)$.

$$\pi_t^{food} = \pi_{t-1}^{food} + \varphi_1\left(\pi 4_{t-1}^{headline} - \pi 4_{t-1}^{food}\right) - \varphi_2\left(p_{t+4}^{food} - p_{t+4}^{core} - \overline{rp}_{t+4}^{food}\right) + \Gamma_{monsoon}(L)\varepsilon_t^{monsoon} + \Gamma_{MSP}(L)\varepsilon_t^{MSP} + \Gamma_{vegetables}(L)\varepsilon_t^{vegetables} + \varepsilon_t^{\pi^{food}}$$

$$\varphi_1 = 0.025;\ \varphi_2 = 0.75 \qquad \ldots(2)$$

Core inflation (π_t^{core}) depends on expected inflation ($E_t{}^h(\pi 4_{t+1}^{core})$), its own past ($\pi_{t-1}^{core}$) to capture the persistence in inflation, the domestic output gap ($\hat{y}_t^{nag}$) and the real exchange rate gap ($\hat{z}_t$). $\left(p_t^{energy,mkt} - p_t^{core} - \overline{rp}_t^{energy,mkt}\right)$, $\left(p_{t+4}^{food} - p_{t+4}^{core} - \overline{rp}_{t+4}^{food}\right)$ represent spillovers from fuel and food components, respectively.[6]

$$\pi_t^{core} = \beta_1 * E_t{}^h(\pi 4_{t+1}^{core}) + (1-\beta_1) * \pi_{t-1}^{core} + \beta_2 * (\hat{y}_t^{nag} + \beta_3 * \hat{z}_t) + \beta_4 * \left(\pi 4_{t-1}^{headline} - \pi 4_{t-1}^{core}\right) + \beta_5\left(p_t^{energy,mkt} - p_t^{core} - \overline{rp}_t^{energy,mkt}\right) + \beta_6\left(p_{t+4}^{food} - p_{t+4}^{core} - \overline{rp}_{t+4}^{food}\right) + \varepsilon_t^{\pi^{core}}$$

$$\beta_1 = 0.33;\ \beta_2 = 0.15;\ \beta_3 = 0.05;\ \beta_4 = 0.01;\ \beta_5 = 0.02;\ \beta_6 = 0.04. \qquad \ldots(3)$$

In the fuel block, inflation (π_t^{fuel}) is determined as the weighted average of petrol and diesel inflation ($\pi_t^{fuel,mkt1}$), LPG and kerosene inflation ($\pi_t^{fuel,mkt2}$) and administered fuel inflation ($\pi_t^{fuel,adm}$).[7]

$$\pi_t^{fuel} = wt_{fuel,mkt1}\,\pi_t^{fuel,mkt1} + wt_{fuel,mkt2}\,\pi_t^{fuel,mkt2} + \left(1 - wt_{fuel,mkt1} - wt_{fuel,mkt2}\right)\pi_t^{fuel,adm}$$

$$wt_{fuel,mkt1} = 0.25;\ wt_{fuel,mkt2} = 0.20. \qquad \ldots(4)$$

Petrol and diesel inflation is determined by changes in the Indian basket of crude oil prices (Δp_t^{oil}), changes in the exchange rate (ΔS_t) and changes in fuel taxes ($\pi_t^{fuel,tax}$).

$$\pi_t^{fuel,mkt1} = \beta_1^{fm1}\pi_{t-1}^{fuel,mkt1} + \beta_2^{fm1}\pi_t^{fuel,tax} + \left(1 - \beta_1^{fm1} - \beta_2^{fm1}\right)4\left(\Delta S_t + \Delta p_t^{oil} - \Delta\bar{Z}_t\right) + \varepsilon_t^{\pi^{fuel,mkt1}}$$

$\beta_1^{fm1} = 0.00$ for immediate and full passthrough and > 0.00 for delayed passthrough

$$\beta_2^{fm1} = 0.47.^{8} \qquad \ldots(5)$$

The changes in tax is assumed to be driven by exogenous factors, *i.e.*,

$$\pi_t^{fuel,tax} = \pi_{t-1}^{fuel,tax} + \varepsilon_t^{\pi^{fuel,tax}} - \varepsilon_{t-1}^{\pi^{fuel,tax}} \qquad \ldots(6)$$

LPG and kerosene inflation is determined by changes in the Indian basket of crude oil prices (Δp_t^{oil}) and changes in the exchange rate (ΔS_t).

$$\pi_t^{fuel,mkt2} = \beta_1^{fm2}\pi_{t-1}^{fuel,mkt2} + \left(1 - \beta_1^{fm2}\right)4\left(\Delta S_t + \Delta p_t^{oil} - \Delta\bar{Z}_t\right) + \varepsilon_t^{\pi^{fuel,mkt2}}$$

[5] Core inflation is defined as inflation excluding food, fuel, petrol and diesel components.

[6] Inflation expectations formation and an endogenous credibility building process is modelled similar to QPM 1.0 (Appendix and Benes *et al.*, 2016b). π denotes quarter-on-quarter (annualised) inflation, while $\pi 4$ denotes year-on-year (y-o-y) inflation. The increase in nominal (S_t) and real (Z_t) exchange rates depicts depreciation and *vice versa.* The relative food price trend is modelled similar to QPM 1.0 (Appendix and Benes *et al.*, 2016b).

[7] In QPM 1.0, fuel inflation incorporated two types of fuel *viz.* market and administered. Market fuel inflation was determined by the Indian basket crude oil prices and exchange rate, while the administered component in fuel pricing was largely modelled as an exogenous process (Benes *et al.*, 2016b).

[8] The coefficient 0.47 corresponds to crude oil prices at around US$80 per barrel.

$\beta_1^{fm2} = 0.00$ for immediate and full passthrough and > 0.00 for delayed passthrough ...(7)

Administered fuel inflation is exogenously determined.

$$\pi_t^{fuel,adm} = \pi_{t-1}^{fuel,adm} + \beta_1^{fa}(\pi_{t-1}^{core} - \pi_{t-1}^{fuel,adm}) + \varepsilon_t^{\pi^{fuel,adm}}$$

$$\beta_1^{fa} = 0.05. \quad ...(8)$$

III.3. Interest Rates Block

The monetary policy repo rate equation follows an inflation forecast-based Taylor-type reaction function with an interest rate smoothing parameter (Benes *et al.*, 2016b).

$$i_t = \lambda_1 i_{t-1} + (1-\lambda_1)\{\bar{r}_t + \pi 4_t^* + \lambda_2 * [E_t(\pi 4_{t+3}^{core}) - \pi 4_t^*] + \lambda_3[E_t(\pi 4_{t+3}^{headline}) - \pi 4_t^*] + \lambda_4 \hat{y}_t^{nag}\} + \varepsilon_t^i$$

$$\lambda_1 = 0.88;\ \lambda_2 = 1.50;\ \lambda_3 = 0.50;\ \lambda_4 = 0.50. \quad ...(9)$$

where i_t is the policy repo rate, $\bar{r}_t$ is the natural rate of interest, $\pi 4_t^*$ is the inflation target, $E_t(\pi 4_{t+3}^{core})$ and $E_t(\pi 4_{t+3}^{headline})$ are the three quarters ahead core and headline inflation forecasts, respectively and $\hat{y}_t^{nag}$ is the output gap. The reaction function contains both core and headline inflation, *i.e.*, monetary policy reacts not only to demand side developments and the underlying inflationary pressures as reflected in core inflation forecasts, but also to supply side pressures pre-emptively as to prevent the second-round effects of food and fuel prices on core inflation. This specification also enables monetary policy to see through transient supply side shocks.

QPM 2.0 incorporates an additional equation for the operating target of monetary policy – weighted average call money rate (WACR) – as follows:

$$\breve{i}_t = i_t + Spread_t \quad ...(10)$$

where $\breve{i}_t$ is WACR and $Spread_t$ is the wedge between the operating target and the policy rate. The steady state value for $Spread_t$ is taken as 0 indicating that in long run, the policy rate and the operating target converge. The transmission from short-term rate to long-term interest rate – relevant for private credit – depends on the term structure of interest rates as well as term premium (Appendix and Benes *et al.*, 2016b).

III.4 Fiscal Block

The fiscal deficit (as per cent of nominal GDP), (FD_t) is the sum of the primary deficit (PD_t) and interest payments (IP_t), *i.e.*,

$$FD_t = PD_t + IP_t \quad ...(11)$$

The primary deficit is decomposed into structural $(PD^s{}_t)$ and cyclical $(PD^c{}_t)$ components, *i.e.*,

$$PD_t = PD^s{}_t + PD^c{}_t \quad ...(12)$$

The cyclical primary fiscal deficit $(PD^c{}_t)$, the automatic stabiliser, is modelled as a function of the economic cycle measured by the output gap $(\hat{y}^{nag})$.

$$PD^c{}_t = -\xi_1 * \hat{y}_t^{nag} + \varepsilon^{PD^c}{}_t$$

$$\xi_1 = 0.2. \quad ...(13)$$

The structural component of the fiscal deficit $(PD^s{}_t)$ is modelled as the weighted average of the one quarter lag of the structural primary deficit and the primary deficit target $(\overline{PD}_t^s)$. Fuel tax changes affect the primary deficit through changes in revenue, *i.e.*,

$$PD_t^s = \rho^{PD^s} * PD^s{}_{t-1} + (1-\rho^{PD^s}) * \overline{PD}_t^s - \xi_2(\pi_t^{fuel,tax} - \pi 4_t^*) + \varepsilon^{PD^s}{}_t$$

$$\rho^{PD^s} = 0.80;\ \xi_2 = 0.002. \quad ...(14)$$

The primary deficit target is calibrated in line with the Fiscal Responsibility and Budget Management (FRBM) path of fiscal consolidation:

$$\overline{PD}_t^s = \rho^{\overline{PD}^s} * \overline{PD}^s{}_{t-1} + (1-\rho^{\overline{PD}^s}) * \overline{PD}_t^s + \varepsilon^{\overline{PD}^s}{}_t$$

$$\rho^{\overline{PD}^s} = 0.70. \quad ...(15)$$

Deviations of the structural primary deficit from its target capture fiscal impulse ($FIMP_t$):

$$FIMP_t = PD_t^s - \overline{PD}_t^s \quad \text{...(16)}$$

Debt accumulation dynamics is modelled as follows:

$$B_t = FD_t + B_{t-1}\left(\frac{1}{\left(1+\frac{\pi 4_t^*+Y4_t^*}{100}\right)}\right) \quad \text{...(17)}$$

where current debt (as per cent of nominal GDP) (B_t) is determined by the current fiscal deficit (FD_t) and the previous level of debt (B_{t-1}) adjusted for nominal GDP growth ($\pi 4_t^* + Y4_t^*$).

The steady state fiscal deficit (FD^*) is related to steady debt dynamics (B^*) as follows:

$$FD^* = B^*\left(1 - \frac{1}{\left(1+\frac{(\pi 4_t^*+Y4_t^*)}{100}\right)} - \frac{i_t^n}{\left(1+\frac{(\pi 4_t^*+Y4_t^*)}{100}\right)} h^{3M} - \frac{i_t^n + prem^{10y*}}{\left(1+\frac{(\pi 4_t^*+Y4_t^*)}{100}\right)}(1-h^{3M})\right)$$

$$h^{3M} = 0.05. \quad \text{...(18)}$$

where i_t^n is the nominal natural rate of interest, which is equal to the real natural rate of interest plus the inflation target. For ease of modelling, we assume that government finances the fiscal deficit by issuing two types of bonds, one of short-term maturity (91-day Treasury Bill) and the other with long-term maturity (10-year G-Sec bonds). h^{3M} represents the share of short-term bonds and $(1-h^{3M})$ represents the share of long-term bonds. $prem^{10y*}$ represents the average spread between short-term and long-term interest rates.

Finally, the debt target ($\overline{B_t}$) anchors government's behaviour and is represented by the following equation:

$$\overline{B_t} = \rho^{\bar{B}}\overline{B_{t-1}} + (1-\rho^{\bar{B}})B^* + \varepsilon^{\bar{B}}{}_t$$

$$\rho^{\bar{B}} = 0.99. \quad \text{...(19)}$$

Overall interest payments (IP_t) are the sum of interest payments on short-term (IP_t^{3M}) and long-term (IP_t^{10Y}) bonds.

$$IP_t = IP_t^{3M} + IP_t^{10Y} \quad \text{...(20)}$$

Interest payment on short-term bonds is the product of the previous period short-term rate ($\check{i}_{t-1}$) and the portion of outstanding debt held as short-term bonds in the previous period ($h^{3M} * B_{t-1}$), adjusted for the changes in nominal GDP growth.

$$IP_t^{3M} = \check{i}_{t-1}\, h^{3M} B_{t-1} \frac{1}{\left(1+\frac{(\pi 4_t^*+Y4_t^*)}{100}\right)} \quad \text{...(21)}$$

Interest payment on long-term bonds is the product of the previous period interest rate (i_{t-1}^{10y}) and the portion of outstanding debt held as long-term bonds in the previous period ($(1-h^{3M}) * B_{t-1}$), adjusted for the changes in nominal GDP growth.

$$IP_t^{10Y} = i_{t-1}^{10y} * (1-h^{3M})B_{t-1} \frac{1}{\left(1+\frac{(\pi 4_t^*+Y4_t^*)}{100}\right)} \quad \text{...(22)}$$

The interest rate (i_t^{10y}) on long-term government securities can be represented as the average of forward-looking short-term interest rates and the term premium ($prem_t^{10y}$).

$$i_t^{10y} = \frac{1}{40}\sum_{i=0}^{39} \widetilde{i_{t+i}} + prem_t^{10y} \quad \text{...(23)}$$

The term premium ($prem_t^{10y}$) is assumed to converge to the long-term average spread between short term and long-term interest rates ($prem^{10y*}$) in the absence of any shock.

$$prem_t^{10y} = \rho^{prem^{10y}} prem_{t-1}^{10y} + (1-\rho^{prem^{10y}})prem^{10y*} + \varepsilon_t^{prem^{10y}}$$

$$\rho^{prem^{10y}} = 0.75. \quad \text{...(24)}$$

III.5 Modified Risk-adjusted Uncovered Interest Parity (MRUIP)

The uncovered interest rate parity (UIP) condition, wherein interest rate differentials determine the expected exchange rate, has been popularly used in small open economy models for monetary policy analysis. However, the UIP relation has been consistently and decisively rejected in the data (see Froot and Thaler, 1990; Lewis, 1995 and Engel, 1996 for comprehensive surveys). To reflect this empirical disconnect, time varying country risk premia and purchasing power parity conditions are introduced to moderate the effects of interest rates on exchange rates (Benes *et al.*, 2016b).

Exchange rate dynamics captured through the MRUIP equation have been modified to incorporate features of external sector: a) an adjustment process for capital flows; b) determinants of current account; c) the balance of payments identity relating the current and capital accounts to the accumulation of reserves; and, d) forex interventions.

$$K_t = \varsigma_1 K_{t-1} + \varsigma_2 (rr_t - rr_t^{rw}) - \varsigma_3 \Delta S_t + \varsigma_4 (\hat{y}_t^{nag} - \hat{y}_t^{f}) + \varepsilon_t^K$$

$$\varsigma_1 = 0.55;\ \varsigma_2 = 0.05;\ \varsigma_3 = 0.20;\ \varsigma_4 = 0.08. \quad ...(25)$$

where K represents capital flows (as per cent of nominal GDP), which are driven by the real interest rate gap $(rr_t - rr_t^{rw})$; changes in nominal exchange rate (ΔS_t); and the difference between domestic and global output gaps $(\hat{y}_t^{nag} - \hat{y}_t^{f})$;

$$CA_t = \tau_1 CA_{t-1} + \tau_2 \hat{Z}_t - \tau_3 \hat{y}_t^{nag} - \tau_4 \widehat{Oil}_t + \varepsilon_t^{CA}$$

$$\tau_1 = 0.50;\ \tau_2 = 0.07;\ \tau_3 = 0.10;\ \tau_4 = 0.015. \quad ...(26)$$

where CA is the current account balance (as per cent of nominal GDP), which is determined by $\widehat{Oil}$ representing the crude oil price gap[9], domestic demand conditions ($\hat{y}_t^{nag}$) and the real exchange rate gap ($\hat{Z}_t$).

The change in reserves (as a per cent of nominal GDP (ΔRes)) represents the balance of payments identity conditioned by forex interventions (Int) which, in turn, determines the impact of capital flows on the exchange rate.

$$Int(CA_t + K_t) = \Delta Res_t$$

$$Int = 0\ for\ no\ intervention\ and\ 1\ for\ full\ intervention. \quad ...(27)$$

Incorporating the added features, the MRUIP equation is expressed as follows:

$$\gamma_1 * [\breve{\imath}_t - (i_t^f + \sigma_t + \gamma_2 * BIMP_t + \gamma_3 * FIMP_t)] + (1-\gamma_1) * [4\Delta\bar{Z}_{t-1} + (\pi4_{t-1}^{core} - \pi4_{t-1}^{f})] + (1 - Int) * \gamma_4 * K_t = 4 * (E_t S_{t+1} - S_t) + \varepsilon_t^S$$

$$\gamma_1 = 0.55;\ \gamma_2 = 2.0;\ \gamma_3 = 2.0;$$
$$Int = 0\ to\ 1;\ \gamma_4 = 3.33. \quad ...(28)$$

$$E_t S_{t+1} = \delta_1 * S_{t+1} + (1-\delta_1) * \{S_{t-1} + 2 * [\Delta\bar{Z}_t + (\pi4_t^{*} - \pi4_t^{*f})/4]\}$$

$$\delta_1 = 0.63. \quad ...(29)$$

where, S_t is exchange rate, $E_t S_{t+1}$ is expected exchange rate, $\breve{\imath}_t$ is short-term nominal interest rate, i_t^f is foreign nominal interest rate[10], σ_t is time-varying country risk premium, $\pi4_t^f$ is foreign inflation, $\pi4_t^{core}$ is domestic core inflation, $\Delta\bar{Z}_t$ is change in real exchange rate trend, $\pi4_t^*$ and $\pi4_t^{*f}$ are inflation targets of the domestic and foreign economies, $FIMP_t$ is fiscal impulse, $BIMP_t$ is debt impulse and K_t is capital flows.

III.6. Foreign Block

The foreign block in QPM has two parts – the United States (US) block and rest of the world (RoW) block. The US block is a barebone new-Keynesian model with three behavioural equations – the IS curve, the Philips curve and the Taylor rule:

$$\hat{y}_t^{US} = a_1 * E_t(\hat{y}_{t+1}^{US}) + a_2 * \hat{y}_{t-1}^{US} - \alpha_3 * \hat{r}_t^{US} + \varepsilon_t^{\hat{y}^{US}}$$

$$a_1 = 0.25;\ a_2 = 0.55;\ a_3 = 0.20. \quad ...(30)$$

$$\pi_t^{US} = b_1 * E_t{}^h(\pi_{t+1}^{US}) + (1-b_1) * \pi_{t-1}^{US} + b_2 * \hat{y}_t{}^{US} + \varepsilon_t^{\pi^{US}}$$

$$b_1 = 0.75;\ b_2 = 0.10. \quad ...(31)$$

$$i_t{}^{US} = c_1 i_{t-1}{}^{US} + (1-c_1) * \{\bar{r}_t{}^{US} + \pi4_t^{*US} + c_2 * [E_t(\pi4_{t+3}^{US}) - \pi4_t^{*US}] + c_3 * \hat{y}_t{}^{US}\} + \varepsilon_t^{i^{US}}$$

$$c_1 = 0.70;\ c_2 = 1.50;\ c_3 = 0.20. \quad ...(32)$$

9 Deviation of crude oil price from its long-term trend.

10 The foreign interest rate (i_t^f) is approximated using fed funds rate ($i_t{}^{US}$).

where $\hat{y}_t^{US}$ is the US output gap, $\hat{r}_t^{US}$ is the US real interest rate gap, π_t^{US} is the US inflation, ${i_t}^{US}$ is the Fed funds rate, $\pi4_t^{*US}$ is the US inflation target and ${\bar{r}_t}^{US}$ is real natural rate of interest of the US.

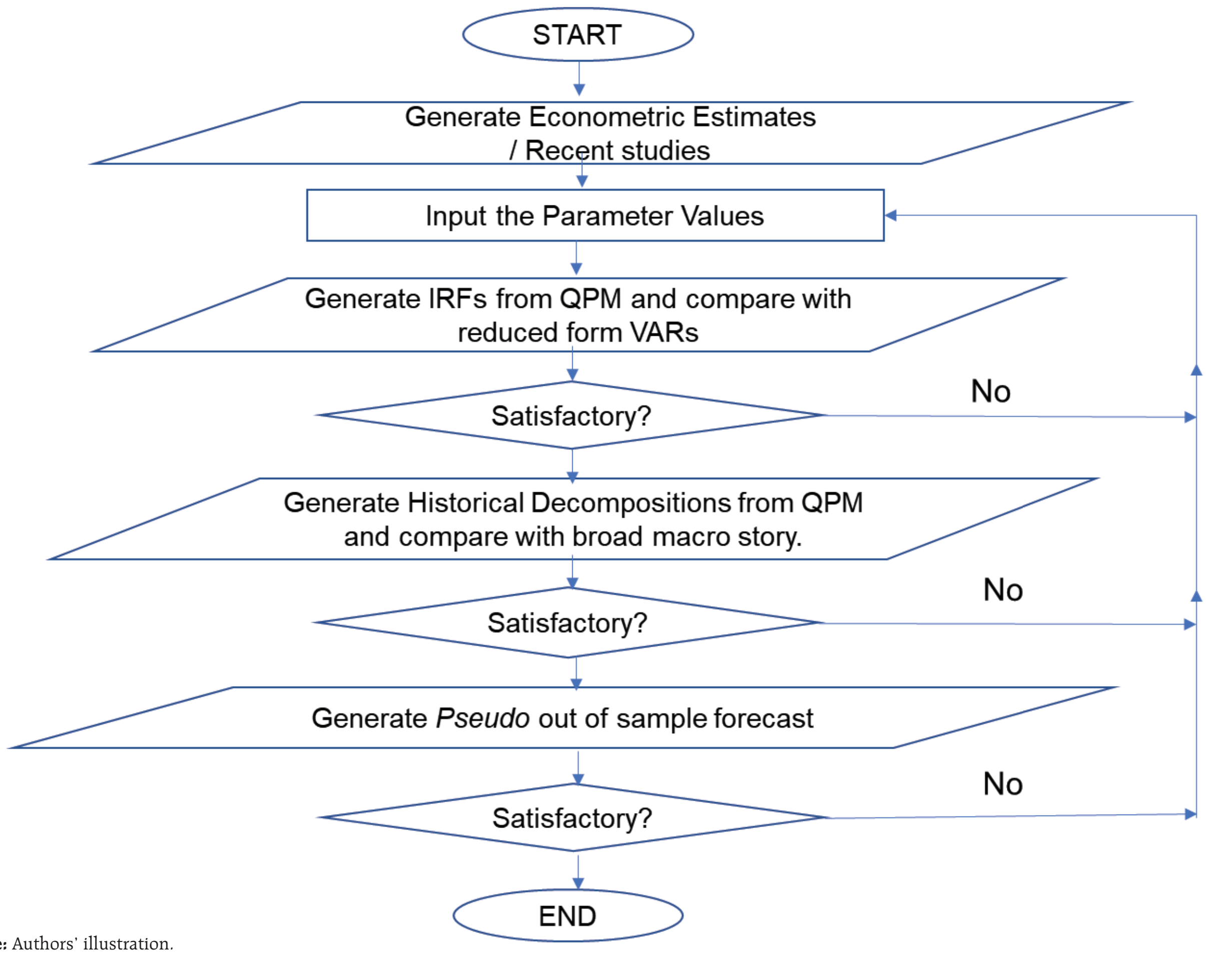
The RoW section of the foreign block incorporates an exogenous equation for crude oil price movements. The forecasts of foreign variables are exogenously provided, based on the information available from agencies like the United States Federal Reserve (US Fed), the International Monetary Fund (IMF) and the International Energy Association (IEA).

III.7. Calibration

The calibration of parameters of QPM 2.0 has been carried out through multiple iterations (Chart 2). This process includes a) generating econometric estimates by using linear regression models, non-linear regression models and vector auto regression (VAR) models; (b) using estimates from other empirical studies (Khundrakpam and Jain, 2012; Misra and Trivedi, 2016; Behera *et al.* 2017; Patra *et al.*, 2018; Kapur, 2018; RBI, 2018; Goyal and Parab, 2019; Raj *et al.*, 2018; RBI, 2019; Patra *et al.*, 2021; Pattanaik *et al.*, 2022); and (c) evaluating the fit by using model generated IRFs, historical decompositions and rolling forecasts.

Model solutions, simulations, historical decompositions and forecasts are carried out using the IRIS toolbox in MATLAB through following steps. First, the model needs to be linearised around a

Chart 2: Flow Chart – QPM 2.0 Calibration



Source: Authors' illustration.

steady state. Second, dynamic solutions involving the forward-looking variables have to be obtained. Third, unobserved variables have to be filtered out from the state-space representation. Fourth, forecasts and policy simulations have to be generated.

Steady states are computed by using a nonlinear Newton-type algorithm. The dynamic model solution is obtained from a nonlinear particle swarm optimizer (PSO), and a generalised Schur decomposition is used to integrate future expectations. The unobserved variables are filtered out by employing a multivariate Kalman filter (MvKF) with an exact nonlinear prediction step. The simulations generated from the model are based on a first-order approximate solution calculated around the steady state. The forecasts are generated by applying equation-selective nonlinear simulator with shanks acceleration.

IV. Model Simulations

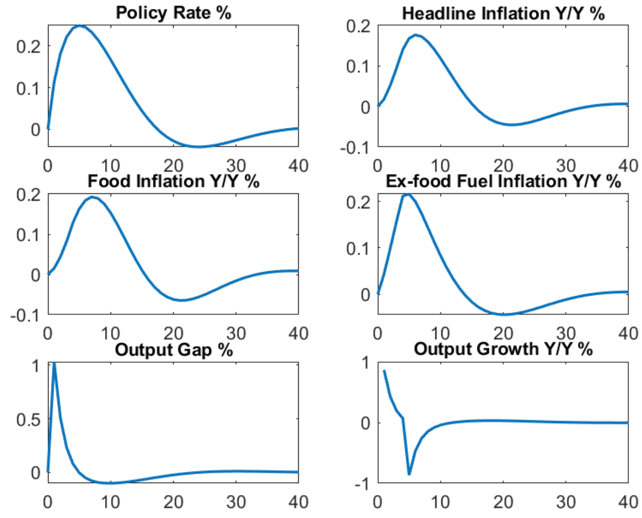
IV.1. Output Gap (Demand) Shock

A positive demand shock of 1 percentage point (ppt) increases core inflation by 20 basis points (bps) at its peak. Headline inflation increases by around 20 bps. Both the output gap and the deviation of inflation from its target require an increase in the real interest rate, which is achieved through a hike in the policy interest rate. These changes dampen demand and over the medium-term, output returns to its potential level. With the elimination of excess demand, inflation returns to the target and all the real variables return to their long-term equilibrium (Chart 3).

IV.2. Core Inflation (Cost-push) Shock

A cost-push shock to core inflation presents monetary policy with a difficult trade-off. The policy rate has to be increased to ensure that inflation returns to target in the medium-term, but this opens up a negative output gap (Chart 4). With the unwinding of the interest rate as inflation falls to target, the output gap closes and output returns to its potential level.

Chart 3: Response to a 1 Percentage Point Increase in the Output Gap

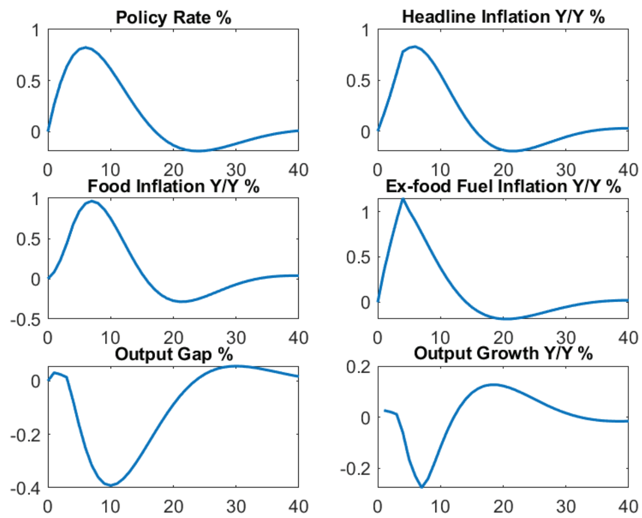


Note: x-axes are quarters; y-axes are percentage points.
Source: Authors' estimates.

IV.3. Policy Rate Shock

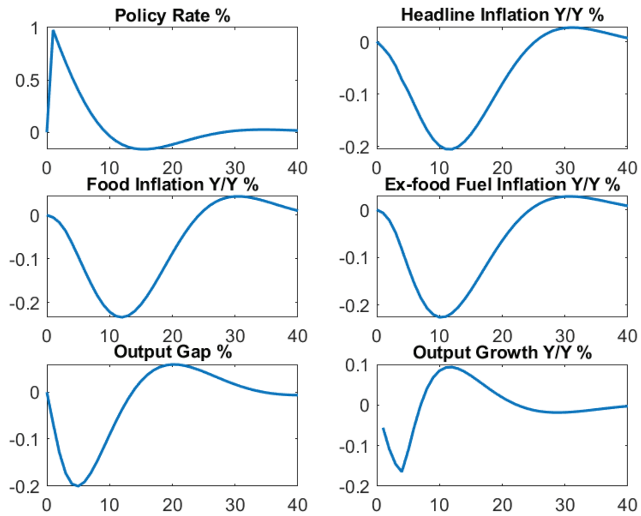
A policy interest rate increase by 1 percentage point results in a fall in domestic demand by around 20 bps and a negative output gap opens up (Chart 5). Along with anchoring of inflation expectations and enhanced

Chart 4: Response to a 1 Percentage Point Increase in Core Inflation



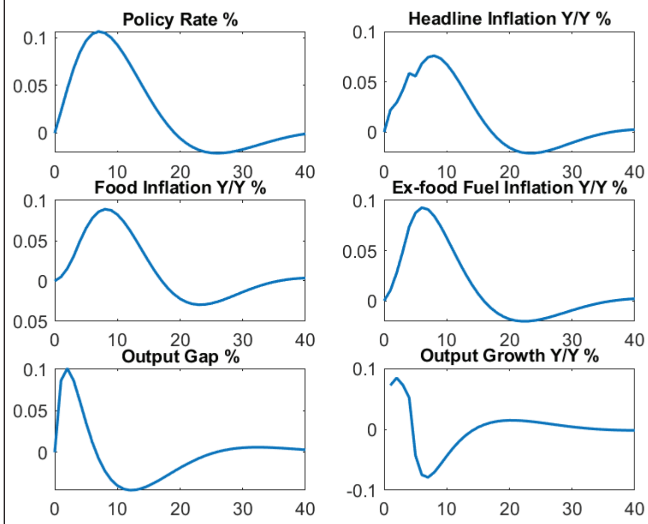
Note: x-axes are quarters; y-axes are percentage points.
Source: Authors' estimates

Chart 5: Response to a 1 Percentage Point Increase in the Policy Rate



Note: x-axes are quarters; y-axes are percentage points.
Source: Authors' estimates

Chart 6: Response to a 1 Per cent Increase in the Exchange Rate



Note: x-axes are quarters; y-axes are percentage points.
Source: Authors' estimates

central bank credibility, this leads to a decline in core inflation by around 25 bps and headline inflation by around 20 bps. These effects, however, hold only in the short run. Over time, as inflation returns to the target, the interest rate decreases, which closes the output gap and neutralises the disinflationary effect of the initial interest rate increase.

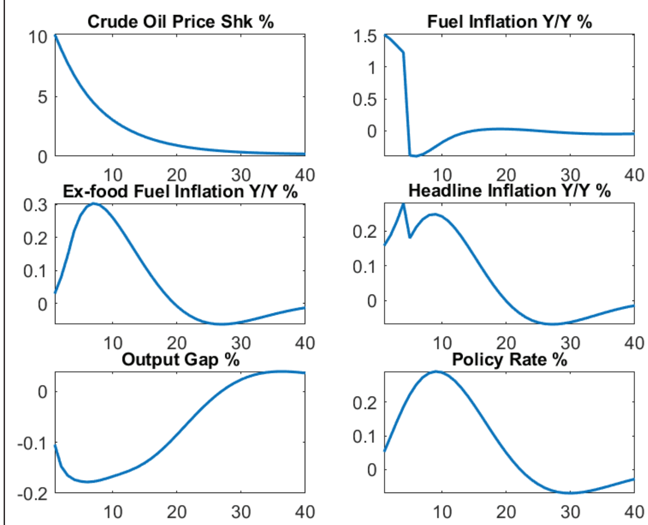
IV.4. Exchange Rate Shock

A depreciation in the exchange rate by 1 per cent leads to increase of around 7 bps in inflation *via* an exchange rate pass-through (ERPT) of 7 per cent (Chart 6). The output gap initially increases as a result of gains in external competitiveness. The increase in inflation and the output gap warrants monetary tightening. This leads to undershooting of the output gap, creating negative growth responses in the medium-term.

IV.5. Crude Oil Price Shock

An increase in global crude oil prices has direct effects on petrol, diesel, LPG and kerosene prices. The increase in market fuel prices induces a cost push shock and core inflation goes up. Higher crude oil prices also induce depreciation of the Indian Rupee (INR). This will have additional second round effects on inflation. Together, an increase in crude oil price by 10 per cent results in inflation increasing up by 30 bps at its peak (Chart 7). Aggregate demand slows down as

Chart 7: Response to a 10 Per cent Increase in the Crude Oil Price



Note: x-axes are quarters; y-axes are percentage points/Per cent.
Source: Authors' estimates

firms take a hit on their profit margins, cash flows and investment. The increase in inflationary pressures, however, warrants a monetary policy response to bring inflation back to target.

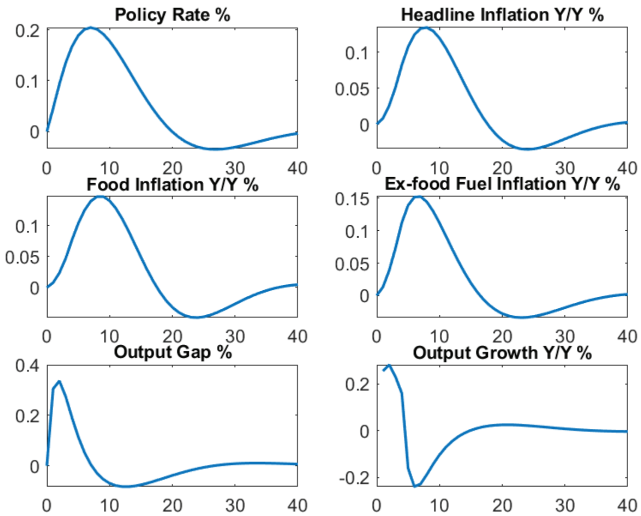
IV.6. World Output Gap (Demand) Shock

An increase in world demand by 1 percentage point leads to increase in domestic demand by 30 bps (Chart 8), which pushes up inflation. The increase in world demand also raises international crude oil prices. With India being an importer of crude oil, the higher crude oil prices exert additional pressure on headline and core inflation. The increase in domestic demand and inflation warrants tightening of monetary policy.

IV.7. Fuel Tax Shock

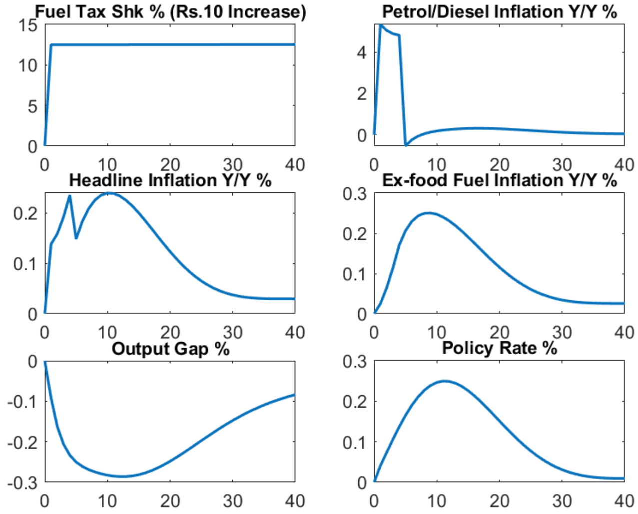
Fuel tax increases are sporadic and non-mean reverting. Hence, in QPM 2.0, the shocks to fuel taxes are assumed not to revert to their original values unless and until they are reversed exogenously. An increase in the fuel tax by ₹10 per litre leads to an increase in fuel prices and hence core inflation through

Chart 8: Response to a 1 Percentage Point Increase in the World Output Gap



Note: x-axes are quarters; y-axes are percentage points.
Source: Authors' estimates

Chart 9: Response to a ₹10 per litre Increase in the Fuel Taxes



Note: x-axes are quarters; y-axes are percentage points/Per cent.
Source: Authors' estimates

the cost push channel. Inflation goes up by 25 bps (Chart 9). Inflationary pressures remain entrenched in the system due to the non-reversal of the increases. Demand conditions also remain subdued for a longer period for the same reason. The policy rate needs to increase to anchor inflationary expectations and neutralise second-round effects.

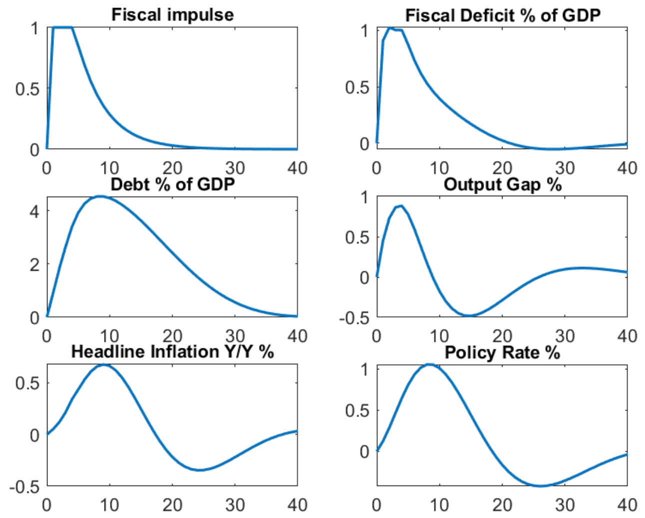
IV.8. Structural Primary Fiscal Deficit Shock

An increase in the structural primary fiscal deficit by 1 percentage point of GDP contributes to demand and opens up a positive output gap (Chart 10). The overall fiscal deficit goes up by the same amount, leading to accumulation of debt, which contributes to depreciation of the INR through country risk premium. The positive output gap and currency depreciation lead to higher inflation, warranting monetary policy action.

IV.9. Capital Flow Shock

The impact of capital flow shock (one percentage point of GDP) is conditional on the RBI's decision to intervene and sterilise. In case of a capital outflow

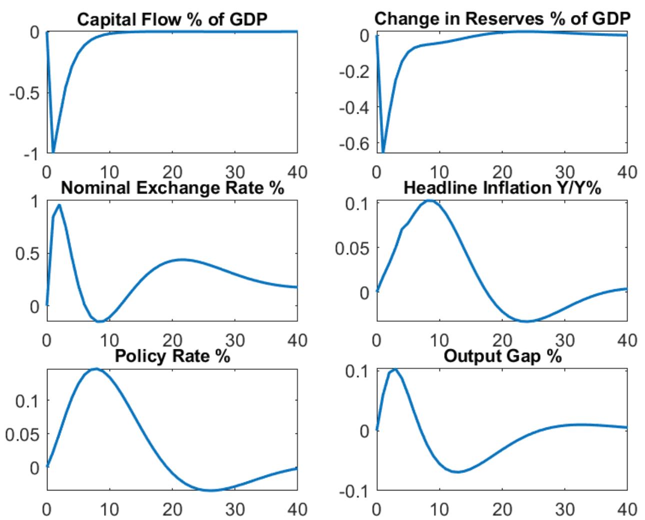
Chart 10: Response to a 1 Percentage Point Increase in the Structural Primary Deficit



Note: x-axes are quarters; y-axes are percentage points.
Source: Authors' estimates

shock, assuming the RBI intervenes and sterilises 70 per cent, the reserves will deplete by 0.7 percentage point of nominal GDP. In this scenario, the exchange rate could depreciate by close to 1 per cent, inducing inflation of around 10 bps (Chart 11).

Chart 11: Response to a 1 Percentage Point Decline in Capital Flows



Note: x-axes are quarters; y-axes are percentage point/Per cent.
Source: Authors' estimates

If the central bank decides not to intervene, there will be no depletion of reserves; however, the depreciation could be higher, leading to higher inflation and higher policy rates and imparting volatility to the exchange rate, inflation and policy rate. On the other hand, if the central bank chooses to intervene fully, an equal amount of reserves will be depleted and the exchange rate will remain more or less unchanged, warranting no monetary policy rate changes but with volatility in reserves.

V. Historical Decompositions

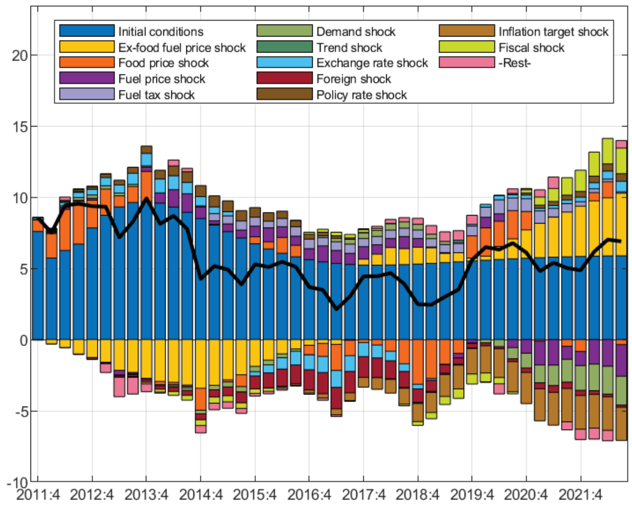
A historical decomposition (HD) of the major macro variables for the period 2011-2022 helps to understand the role of various shocks and policies in driving the trajectory of macroeconomic developments.

V.1. Headline Inflation

Prior to 2014 – the period which laid down the initial conditions of the FIT – headline inflation was in double digits. Food price shocks emanating from the monsoon and MSP, the lack of a nominal anchor, exchange rate depreciation and high fuel prices drove inflation up during that period (Chart 12). During 2014 to 2016, when a *de facto* FIT framework was pursued, the factors that contributed to high inflation during the pre-2014 period dissipated. Cost push shocks became disinflationary on the back of benign global commodity prices and exchange rate stability was restored as the external environment turn favourable. From 2014 onwards, fuel taxes started to contribute positively to inflation, offsetting the negative impact of the crude oil price decline. Owing to these factors, inflation steered close to 4 per cent by the time FIT was institutionalised in 2016.

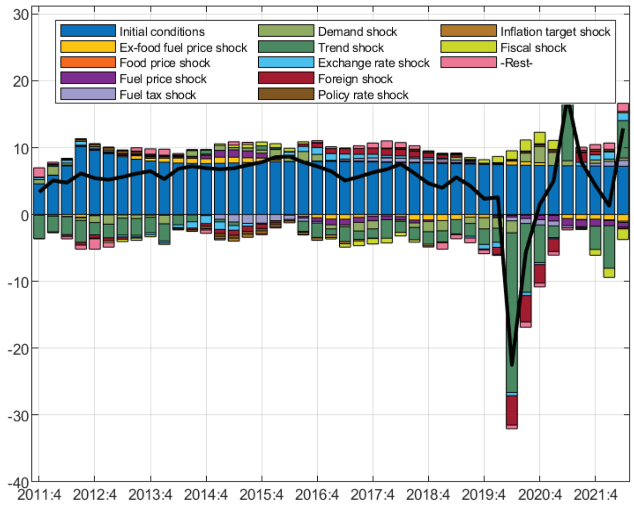
From 2016 onwards, the nominal anchor set out by the FIT contributed favourably to inflation. Fiscal prudence also contributed to the disinflationary process. Up till Q3:2019, food price shocks led to a fall in inflation. Fuel price shocks were also favourable during this period.

Chart 12: Historical Shock Decomposition of Headline Inflation



Source: Authors' estimates

Chart 13. Historical Shock Decomposition of GDP Growth



Source: Authors' estimates

During the 2020-22 period, food price and cost-push shocks emanating from persistent supply chain disruptions due to the COVID pandemic and the war in Ukraine exerted upside pressure on headline inflation, partly offset by subdued demand conditions.

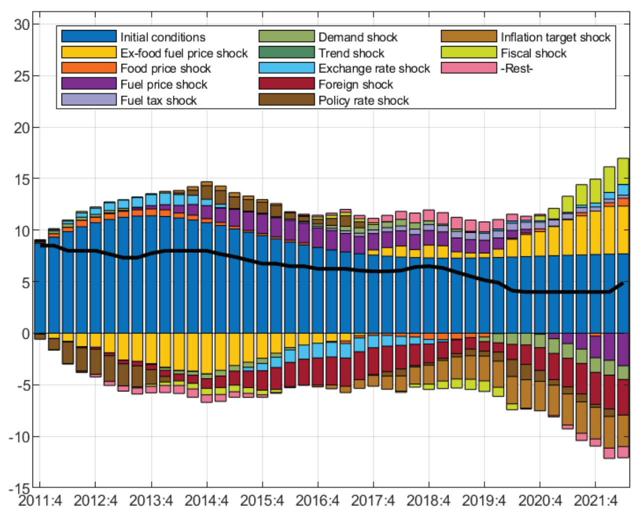
V.2. GDP Growth

The HD of GDP growth suggests that potential output shocks and structural factors were mostly responsible for the GDP growth slowdown during 2016-19 (Chart 13). The pandemic induced lockdown, supply chain bottlenecks and weak external demand adversely impacted domestic output and demand during 2020-22.

V.3. Policy Repo Rate

In the 2014-16 period, the stability in the exchange rate, favourable cost-push shocks and a conducive external environment contributed negatively to the policy rate. During the FIT period (2016 -2019), favourable food and fuel price shocks, external developments and fiscal prudence supported a lower policy rate environment (Chart 14). Most interestingly, the nominal anchor set out by the FIT contributed negatively to the policy rate during this phase. In other words, in the absence of a nominal anchor, the policy rate could have been higher in order to achieve the same level of inflation. This indicates that with an explicit nominal anchor, the monetary policy rates can afford to be raised less than otherwise for disinflating the economy.

Chart 14. Historical Shock Decomposition of Policy Repo Rate



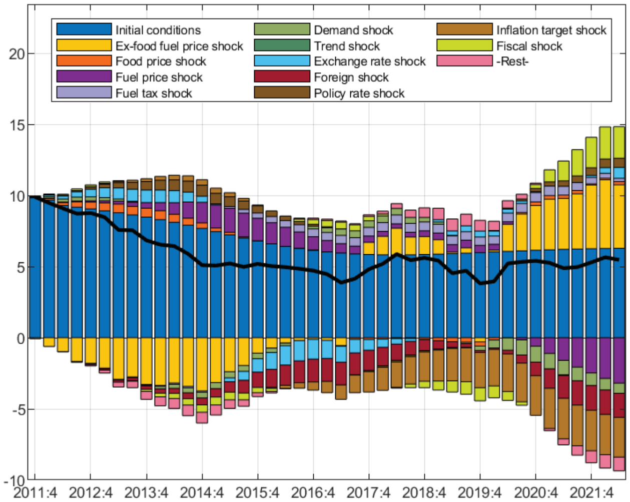
Source: Authors' estimates

During 2020-22, a large negative output gap due to the pandemic caused monetary policy to follow an accommodative stance. From May 2022, the policy repo rate has been increased in a calibrated manner in view of headline inflation ruling above the target along with elevated core inflation.

V.4. Core Inflation

HD of core inflation is similar to that of headline inflation. The institution of the FIT regime, benign crude oil prices, fiscal prudence and favourable external environment provided cushions to core inflation during 2016-19, which more than offset the upside pressures from the increase in fuel taxes (Chart 15). Pandemic induced supply chain disruptions and cost push shocks led to elevated core inflation in 2020-22.

Chart 15. Historical Shock Decomposition of Core Inflation

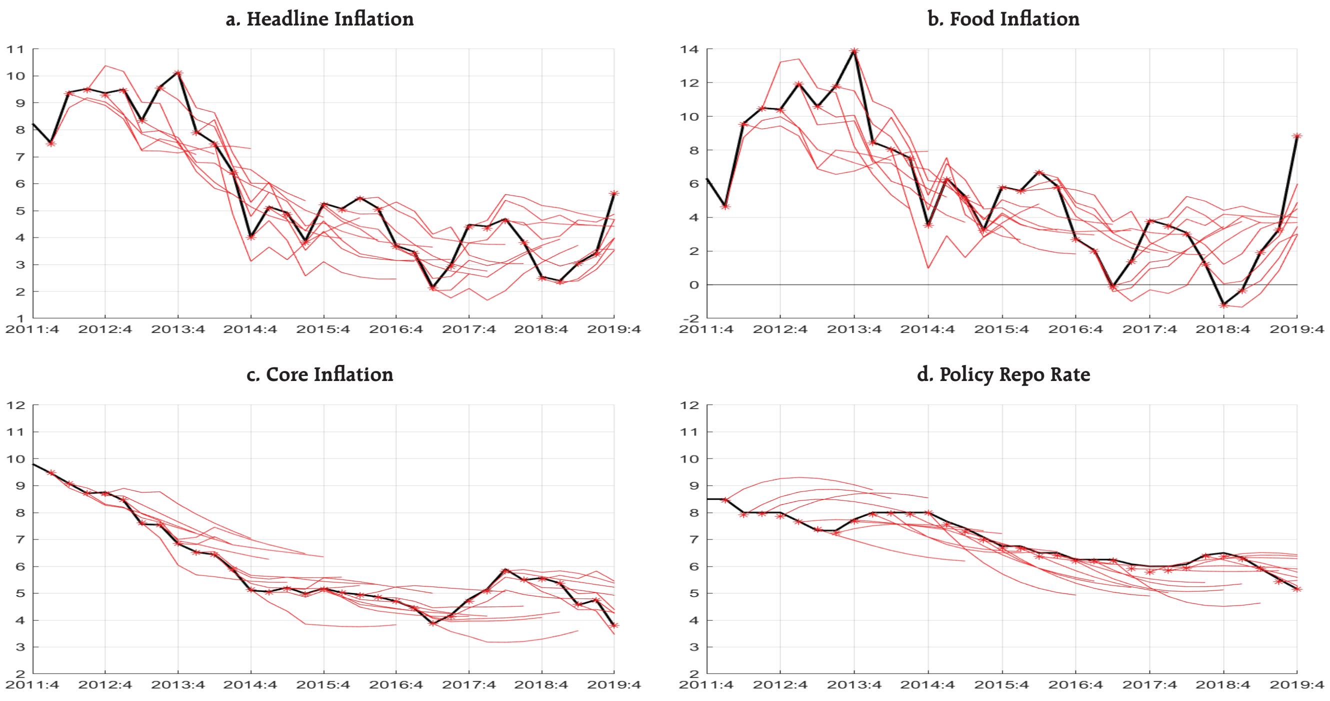


Source: Authors' estimates

VI. Forecast Performance

This section evaluates the forecast performance of QPM 2.0 by generating *pseudo* out-of-sample forecasts of up to 8 quarters ahead and calculating the *pseudo* out-of-sample root mean square errors (RMSE) of major macroeconomic variables for the period from 2011 to 2019 (Chart 16).

Chart 16: Actual *Versus* Pseudo Out-of-sample Forecasts (per cent)



Source: Authors' estimates

The hairline charts indicate that the forecasts of food inflation and headline inflation appear to be directionally consistent. Core inflation and policy rate forecasts seem to be less noisy than food and headline inflation forecasts.

A formal evaluation of the forecast is conducted by generating the *pseudo* out-of-sample RMSEs over various forecast horizons (Table 2).

The RMSEs of the headline inflation forecasts in the short to medium horizon (1-4 quarters) are marginally higher than that of time series forecasts and are comparable with that of the Survey of Professional Forecasters (SPF) (John *et al.*, 2020; Raj *et al.*, 2020). RMSEs of the best time series forecasts are 0.2 to 0.6 percentage points lower in 1-4 quarters. This behaviour is expected as large macroeconomic models tend to produce larger errors in the short-term relative to models based on time series and full information matrices. This is also the reason why the QPM uses forecasts from short-term forecasters as its initial condition. The forecast performance substantially improves in the medium horizon (5-8 quarters), which matters for the monetary policy decision. In the eight-quarter ahead forecasts, QPM turns out to be better than time series models (John e*t al.*, 2020) by a substantial margin.

The RMSEs of core inflation forecasts are substantially lower than that of the headline inflation, as expected. As in the case of headline inflation, RMSEs of core inflation forecasts from QPM are higher than time series forecasts and comparable to SPF forecasts over the 1-4 quarter horizon (John *et al.*, 2020). In the medium horizon, however, QPM 2.0's forecast accuracy is better than time series model forecasts (John *et al.*, 2020) by considerable margins.

Table 2: *Pseudo* Out-of-sample RMSEs

(percentage points)

Variable / Horizon(Quarters)	0	1	2	3	4	5	6	7	8
Headline Inflation (Per cent, y-o-y)	0.05	0.80	1.07	1.40	1.61	1.50	1.34	1.30	1.21
Food Inflation (Per cent, y-o-y)	0.05	1.60	2.04	2.59	2.91	2.63	2.48	2.55	2.32
Core Inflation (Per cent, y-o-y)	0.03	0.32	0.54	0.73	0.96	0.98	0.99	0.99	0.96
Policy Rate (Per cent)	0.09	0.34	0.58	0.73	0.82	0.91	0.92	0.88	0.79

Source: Authors' estimates.

VII. Conclusion

Given the transmission lags which characterise the impact of monetary policy on output and inflation, forward-looking responses to expected inflation and output are warranted to maximize welfare. Both inflation and output are also shaped by expectations of future interest rates, as also inflation expectations of households and firms. Thus, inflation and output are the outcome of a complex web of interactions and feedback mechanisms in the economy. Accordingly, consistent and reliable forecasts of inflation and output are important as they assume the role of intermediate target of monetary policy. It is in this context that theoretically consistent and empirically well-founded models adapting country-specific features are at the heart of monetary policy formulation among modern central banks.

In India, the adoption of a flexible inflation targeting framework has been underpinned by a Quarterly Projection Model, which fulfils the requirement set out in Section 45ZM of the RBI Act of setting out inflation forecasts for 6-18 months in a half-yearly Monetary Policy Report (MPR).

QPM 2.0 takes that endeavour to the next level by enriching the existing new- Keynesian monetary model (QPM 1.0) with fiscal-monetary policy interactions, a more nuanced modelling of India-specific fuel pricing, capital flows, exchange rate dynamics and central bank's forex market interventions. The QPM 2.0 thus takes monetary policy modelling closer to a general equilibrium framework that is more representative of India's macroeconomic dynamics and helps to generate internally consistent forecasts and policy scenarios. This provides policymakers with relevant information and scenarios for a more informed judgement.

Historical decompositions generated from QPM 2.0 show that the inflationary surge in the wake of the pandemic and the war in Ukraine was triggered by successive supply shocks but as their impact waned, rising demand unleashed by the strengthening domestic recovery enabled pass-through of pent-up input costs, adding persistence to elevated inflationary pressures (Patra *et al.*, 2022). The disinflation strategy adopted during this period has been strongly supported by improved precision in forecasts generated by QPM 2.0 relative to competing models.

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Appendix

Bank-Lending (BL) Condition

BL variable[11] captures frictions in the transmission mechanism of monetary policy on account of bank credit supply conditions. BL not only affects the output gap but is also affected by it. Deviations of the BL from its equilibrium level are, therefore, modelled proportional to future output gap ($\hat{y}_{t+4}^{nag}$) and adjusted for the shock (ε_t^{BL}):

$$BL_t - \overline{BL}_t = -\kappa_1 \cdot \hat{y}_{t+4}^{nag} + \varepsilon_t^{BL}.$$

$$\kappa_1 = 5. \quad \text{...(33)}$$

The output gap is affected by a distributed lag of ε_t^{BL}, denoted by η_t^{BL}, which takes the following form:

$$\eta_t^{BL} = \theta \cdot (0.04\varepsilon_{t-1}^{BL} + 0.08\varepsilon_{t-2}^{BL} + 0.12\varepsilon_{t-3}^{BL} + 0.16\varepsilon_{t-4}^{BL} + 0.20\varepsilon_{t-5}^{BL}$$
$$+0.16\varepsilon_{t-6}^{BL} + 0.12\varepsilon_{t-7}^{BL} + 0.08\varepsilon_{t-8}^{BL} + 0.04\varepsilon_{t-9}^{BL}).$$

$$\theta = 1. \quad \text{...(34)}$$

Inflation Expectations

Inflation expectations are determined by the following process:

$$E_t{}^h(\pi 4_{t+1}^{core}) = (1 - c_t) * \pi 4_{t-1}^{core} + c_t * \pi 4_{t+1}^{core} + \eta_t^{E(\pi 4^{core})}$$

$$\eta_t^{E(\pi 4^{core})} = \rho^{\eta^{E(\pi 4^{core})}} \cdot \eta_{t-1}^{E(\pi 4^{core})} + \varepsilon_t^{E(\pi 4^{core})}.$$

$$\rho^{\eta^{E(\pi 4^{core})}} = 0.4. \quad \text{...(35)}$$

Inflation expectations are a weighted sum of one-quarter lagged year-on-year core inflation, and the model-based rational expectation of year-on-year inflation one quarter ahead. The weights depend on the stock of policy credibility (c_t). c_t can range from 0 (no credibility), in which case expectations are completely backward looking, to 1 (perfect credibility), in which case inflation expectations are perfectly forward looking.

Credibility Stock Building

Credibility, as noted above, is modelled as a stock (c_t) measured between 0 and 1. Credibility changes non-linearly *i.e.*, at lower levels of credibility, monetary policy needs to be sufficiently aggressive to achieve the disinflation. However, as credibility stock increases, the policy reactions can be lower to achieve the same quantum of disinflation.

Credibility can improve only gradually over time, especially, in the initial periods of FIT. Credibility responds to a signal (ξ_t), that is good – if inflation has been converging to the target (π^{good}), and that is bad – if rising towards a high-inflation state (π^{bad}).

$$c_t = \rho^c \cdot c_{t-1} + (1 - \rho^c) \cdot \xi_t.$$

$$\rho^c = 0.95. \quad \text{...(36)}$$

The credibility signal weighs the relative likelihood of inflation converging to the target. It is higher if the current realised inflation is closer to the target. The error under the bad (good) regime is defined as the difference between the realised inflation and the expected inflation under the bad (good) regime.

$$\xi_t = \frac{(\epsilon_t^{bad})^2}{(\epsilon_t^{bad})^2 + (\epsilon_t^{good})^2}. \quad \text{...(37)}$$

$$\epsilon_t^{bad} = \pi 4_t - [\rho^\epsilon \cdot \pi 4_{t-1} + (1 - \rho^\epsilon) \cdot \pi^{bad}]. \quad \text{...(38)}$$

$$\epsilon_t^{good} = \pi 4_t - [\rho^\epsilon \cdot \pi 4_{t-1} + (1 - \rho^\epsilon) \cdot \pi^{good}].$$

$$\rho^\epsilon = 0.5;\ \pi^{bad} = 8.0;\ \pi^{good} = 4.0\,. \quad \text{...(39)}$$

ρ^ϵ is taken to be 0.5 assuming an equal weight for past and expected inflation under the bad (good) regime. The good regime is characterized by 4.0 per cent inflation and the bad regime is characterised by the high levels of inflation (8 per cent).

Long run Interest Rates

The relation between the short-term rate ($\tilde{i}_t$) and the long-term rate (i_t^m) depends on term structure (i_t^4) as well as term premium (i_t^{RISK}).

[11] The increase in BL variable depicts tightening of bank lending condition and *vice versa*.

$$i_t^m = \rho^{i^m} . i_{t-1}^m + \left(1 - \rho^{i_t^m}\right) \cdot (i_t^4 + i_t^{RISK}) + \varepsilon_t^{i^m}$$

$$\rho^{i^m} = 0.1. \qquad \text{...(40)}$$

The term structure of interest rate (i_t^4) is the 4 quarter ahead average of short term rates and term premium is the weighted average of past value as well as the steady state value for i_t^{RISK}.

Long-term real interest rate (r_t^m) is long-term rate (i_t^m) minus expected inflation $(E_t{}^h(\pi 4_{t+1}^{core})$ and real interest rate gap $(\hat{r}_t^m)$ is the deviation of real interest rate (r_t^m) from the natural rate of interest $(\bar{r}_t^m)$.

$$r_t^m = i_t^m - E_t{}^h(\pi 4_{t+1}^{core}) \qquad \text{...(41)}$$

$$\hat{r}_t^m = r_t^m - \bar{r}_t^m \qquad \text{...(42)}$$

Relative Food Price Trends

$$\overline{rp}_t^{food} = \rho^{\overline{rp}^{food}} \overline{rp}_{t-1}^{food} + (1 - \rho^{\overline{rp}^{food}}) \, \overline{rp}^{food^*} + \eta_t^{\overline{rp}^{food}} + \theta \cdot \varepsilon_t^{MSP} + \varepsilon_{1,t}^{\overline{rp}^{food}} \qquad \text{...(43)}$$

$$\eta_t^{\overline{rp}^{food}} = \rho^{\eta^{\overline{rp}^{food}}} \cdot \eta_{t-1}^{\overline{rp}^{food}} + \left(1 - \rho^{\eta^{\overline{rp}^{food}}}\right) \cdot \varepsilon_{2,t}^{\overline{rp}^{food}}. \qquad \text{...(44)}$$

$$\rho^{\overline{rp}^{food}} = 0.9; \; \theta = 0.4; \; \rho^{\eta^{\overline{rp}^{food}}} = 0.9.$$

The relative food price trend $(\overline{rp}_t^{food})$ depends on its past value $(\overline{rp}_{t-1}^{food})$, steady state level $(\overline{rp}^{food^*})$, a moving average process $(\eta_t^{\overline{rp}^{food}})$, shocks to MSPs (ε_t^{MSP}) and idiosyncratic shocks $(\varepsilon_{1,t}^{\overline{rp}^{food}})$.